

# A TECHNICAL APPROACH TO THE MAINTENANCE AND OVERHAUL OF GAS TURBINES

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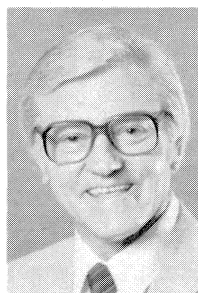
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## ABSTRACT

Conventional approaches to maintenance of large machines are effective, but they often have problems in the areas of record keeping, access to knowledge gained from previous experience, lack of intimate knowledge of individual machines' operating characteristics, and availability of expert advice for emergency repairs.

The author's alternative approach of an in-house, multidisciplinary maintenance team is discussed. This approach includes the specialty areas of lubrication, dynamic balancing and vibration, optical alignment, metallurgical engineering, welding technology, non-destructive testing, mechanical analysis, and mechanical engineering.

## INTRODUCTION

*What you see is what you get!!*

*You expect what you inspect!!*

*The more you know, the more you get!!*

All of these statements apply to a well-maintained production facility. My theme is this: Get your technical people out of their offices and into the field with their hands on the equipment!

It's hard to improve a piece of equipment if you haven't seen, heard, or felt it. How many of you have had your hands on the engine of your favorite automobile? Isn't it great when you can't feel or see the engine move when it's running? How many of you have had your hands on your gas turbines? Did you get the same thrill? If you didn't, there is something wrong.

I suspect there are at least a few businesses that still use one of the conventional approaches to maintaining large machines, including gas turbines:

1. Service contract with original equipment manufacturer.

2. In-house maintenance supervisor and crew, assisted by an outside consultant.

Equipment owners usually have a production or maintenance engineer or technician checking on work, but don't really get involved in problem solving themselves.

These approaches are effective, but there are several potential problems: Usually, adequate records are not kept on mechanical condition before repairs; specific repairs made; and clearances, fits, and finishes when new, before repairs, and after repairs. Knowledge gained from failure analysis often walks out the gate with the consultant and/or repair crew, and it never gets back to the people who own the equipment. The personnel actually responsible for day-to-day operation of machinery often do not learn the characteristics of their machines, the things to watch for, and how to improve the machines' performances. Often, engineers or specialists sitting in remote offices make decisions that affect a machine's performance, though these decision makers have never experienced living with their decisions.

When operating plants get into trouble, where do they get help? Most industries can no longer afford to shut down equipment while waiting for repair consultants to get free from other jobs. Extended downtime is too expensive.

## AN ALTERNATIVE APPROACH

The approach to maintenance implemented in the Dow Texas Division addresses most of these problems. Initially, some basic objectives were established:

1. To create in-house technology, so repairs can be made intelligently and without delay.
2. To operate machines at the maximum efficiency allowable by construction materials, instruments, and operating parameters.
3. Not to shut down a machine for overhaul without a scientific reason for doing so.

### Program Structure

In this approach to maintenance, responsibility is spread among several plant functions. Each of these functions is described briefly:

**Optical Alignment**—The Optical Alignment group works closely with the mechanical analysts at installation and with vibration personnel for initial alignment and vibration analysis. All of our high speed, critical equipment is set on subsole plates and sole plates. These are optically set flat to within .002 in. In some instances, multiple case trains are bore aligned. Tooling balls are installed where possible, and pogo sticks are used for trending and hot alignment checks. Shafts can also be checked for permanent bows. As with the vibration analysts, the optical alignment group's plantwide exposure makes their expertise invaluable at installation and later in trending and troubleshooting. Their hands-on experience lets them know

what a properly running machine feels like.

**Lubrication**—Our Lubrication Department is the cornerstone of the preventive maintenance program. Regular monitoring programs are set up to keep trends of lube oil and transformer oil condition. Ferrography is used for either trending of wear metals or for obtaining precise analytical results. This technique can determine the types of metal present, as well as the wear mode (rub, cut, or abrasion). Figure 1 (100 $\times$ ) and Figure 2 (400 $\times$ ) show wear typical of abrasion. The lube oil had been contaminated by blasting sand. Silica particles are visible. Figure 3 (100 $\times$ ) shows another sample taken 24 hours later. The wear particles are still large and dense. Figure 4 (100 $\times$ ) shows a sample taken after extensive flushing while on line, resulting in a marked decrease both in quantity and size of wear metal. This allowed the plant to run an additional 18 months until a scheduled shutdown.

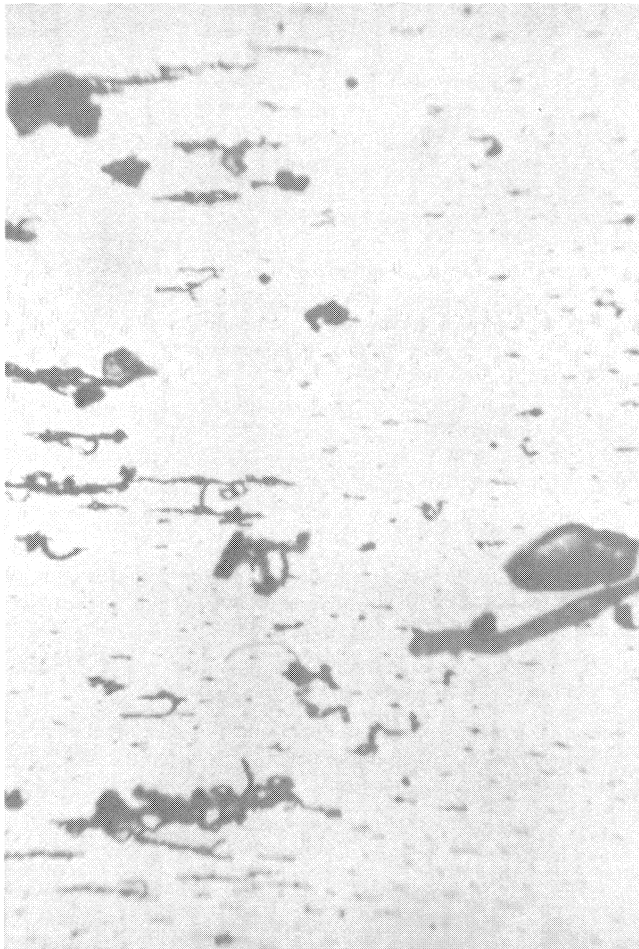


Figure 1. Original Oil Sample (100 $\times$ ).

The Lubrication Department also is knowledgeable in and makes recommendations for types of oils. A case in point was a three bearing gas turbine supplied with a synthetic, fire resistant lube oil. This lubricant was found to be highly hydrolytic, resulting in loss of oxidation resistance. The required alumina treatment was costly and time consuming. The various treatments proposed to reduce the oxidation caused buildup on the thrust bearings, leading to shutdown and downtime for cleanup. It was decided to change to a less costly, high temperature mineral oil and to install a fire protection system. The first batch of this oil now has over 20,000 fired hours without degradation. This type of in-house expertise has

proven itself valuable time and time again, both for troubleshooting and for working with vendor technical personnel.

**Dynamic Balancing and Vibration**—We have our own in-house expertise for dynamic balancing and vibration analysis. This group is responsible for all phases of vendor and repair shop and field work. Complete history and documentation are kept on phase and unbalance effects, resulting in greatly decreased field balancing times. In-house moment weighing and sequencing of blades also has proven valuable in this area. The quality and reliability of data are of great concern. Techni-

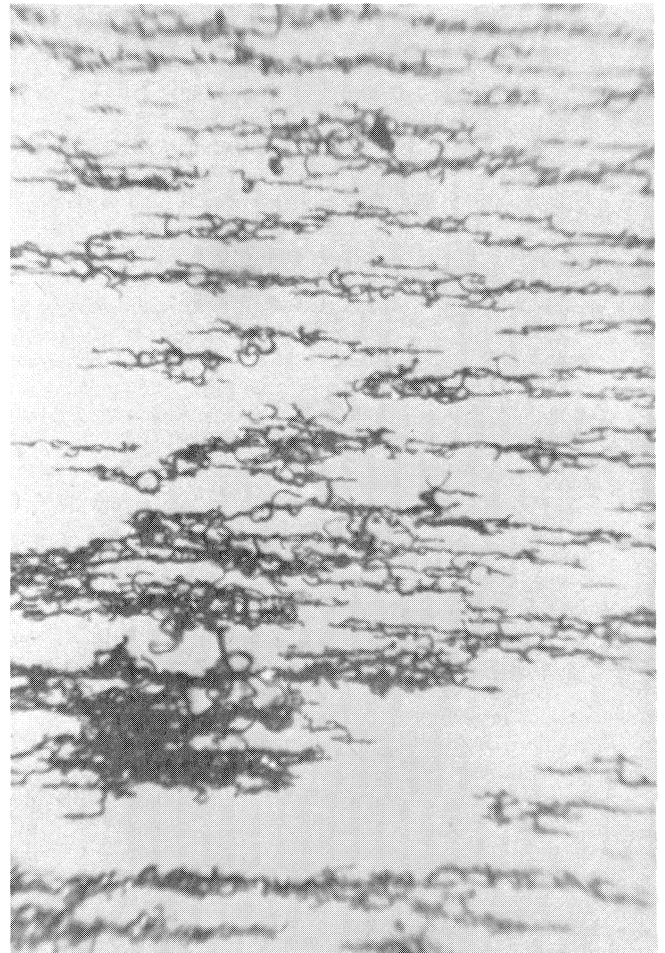


Figure 2. Original Oil Sample (400 $\times$ ).

cians are thoroughly trained in the use of spectrum analyzers and digital vector filters for use in shop inspection, balancing, and trending. Probe areas are burnished to reduce electrical runout, and redundant instrumentation is installed on all critical equipment. By using specialists, who perform these services throughout the plant, we have been able to develop techniques and become well acquainted with the characteristics of machines plantwide, with the net effect being a quicker, more effective balancing and vibration analysis program.

**Metallurgical Engineer**—The metallurgical engineer is responsible for ensuring optimum life and performance through specification of materials, heat-treatments, and coating.

Gas turbine blades, transition pieces, nozzles, and cast vane segments are reheat-treated at the appropriate intervals. Almost infinite lives are now expected from these pieces.

All row 1 and hotter running row 2 turbine blades are platinum aluminide coated (see Figure 5). Even with clean fuel

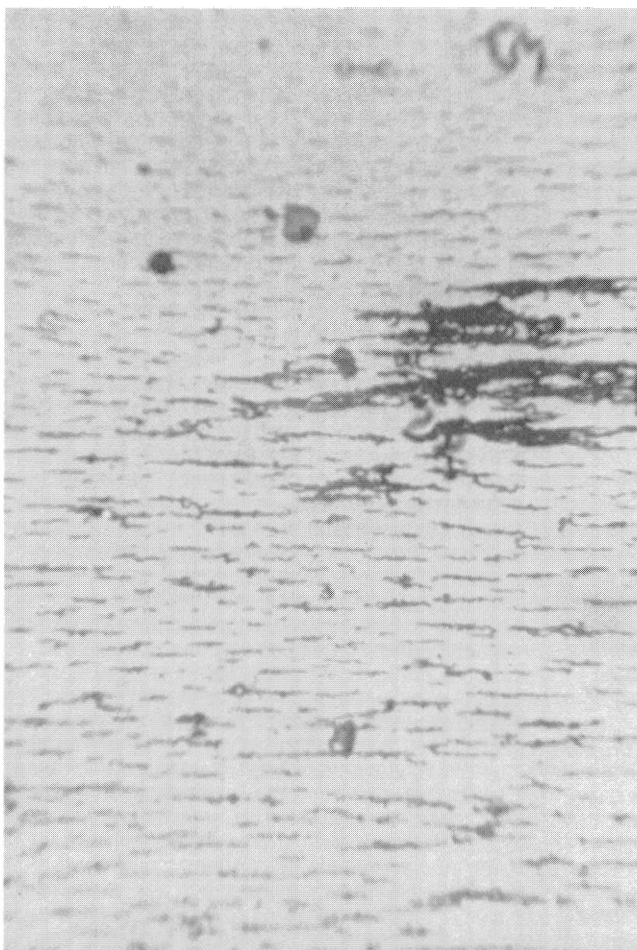


Figure 3. Sample Taken 24 Hours Later (100×).

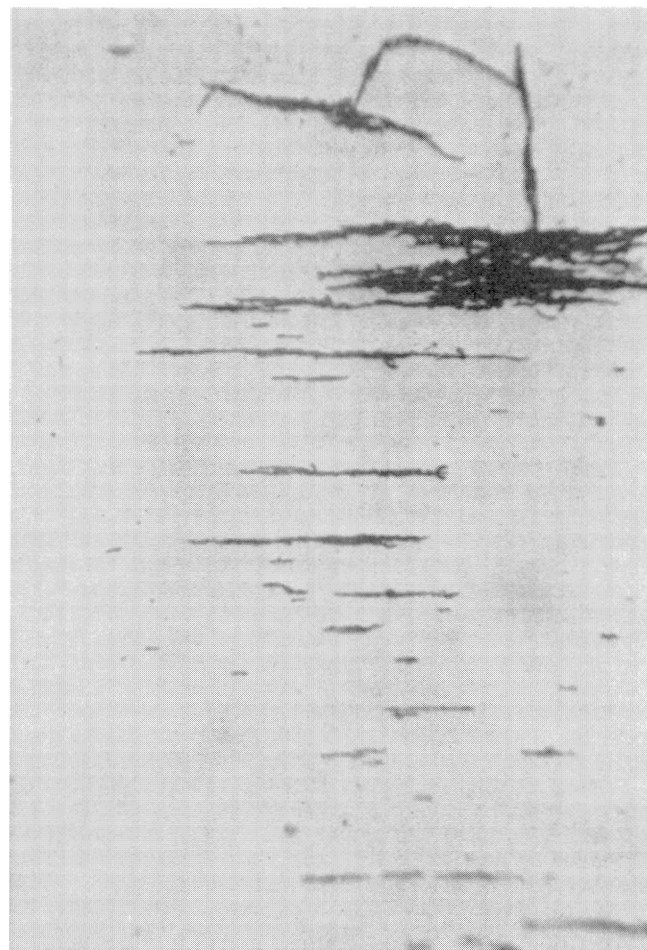


Figure 4. Sample Taken After Flushing (100×).

gas, grain boundary corrosion leading to possible fatigue failures can occur without coating. Weld repairs, especially on combustor parts and nozzle segments, are made better than they have to be. Welding every little crack results in more reliable fixes in the long run.

One example of materials related improvement involves the failure of a second row blade ring segment (see Figure 6). This failure resulted in damage to several downstream turbine blades and vanes. The cause of the failure was determined to be a small piece of ring segment broken off due to embrittlement caused by formation of sigma phase. Future ring segments will be cast from HK40 310 SS rather than sigma prone CH20 309 SS.

We have purchased, or selected vendors for, all compressor and turbine parts with exception of vanes and stationary blades (see Figure 7). These alternate source parts are available at 25-50% of OEM price, with equal or better quality and delivery.

Dow is using coated compressor blades and vanes in almost all of its turbines (see Figures 8 and 9). Both sprayed-on and pack diffused aluminum coatings are being used, but we prefer the pack diffused coatings because of their longer life. Our ongoing study of compressor coatings also includes plasma sprayed titanium dioxide and teflon coatings.

**Welding Technology**—The welding specialist is responsible for working with the metallurgist in determining the cause of failure; determining if the part can be put back into "new" condition; working with designers to determine how safe the failure mode is, i.e., whether the repaired piece needs to be

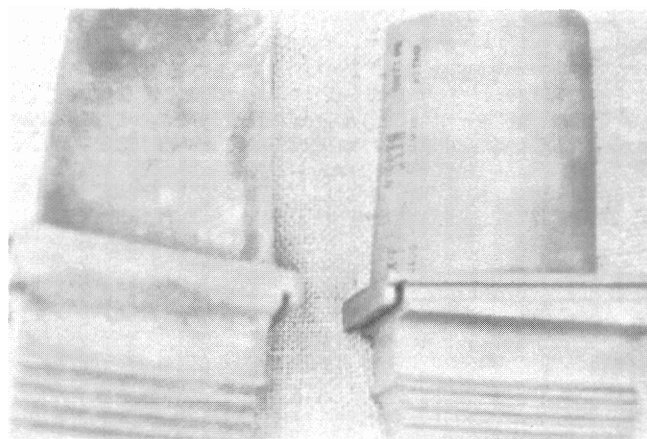


Figure 5. Blade on the Left Was Run Uncoated; Blade on the Right Is a New Coated Blade.

strengthened or redesigned. A partial list of successfully repaired stationary parts is presented in Table 1.

**Non-Destructive Testing**—Dow's NDT group is responsible for assuring structural integrity of all gas path parts, shafts, and fasteners, as well as the determination of coating thicknesses. Dye penetrant or magnetic particle detection techniques are used on the fasteners and thinner pieces such as combustors (see Figures 14, 15, 16, and 17). Special eddy current probes and techniques are used to test blades for

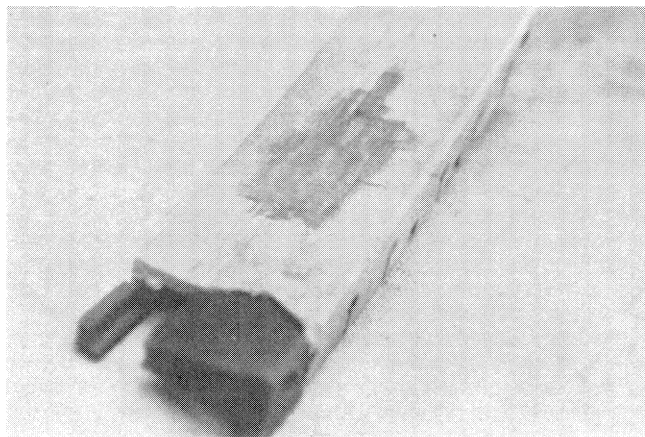


Figure 6. Cracked Blade Ring Segment; Formation of Sigma Phase in CH20 309 SS Caused Embrittlement.

Table 1. Partial List of Successfully Repaired Stationary Parts.

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Steam turbine diaphragms—410 stainless
Combustor baskets—310 stainless and Hastelloy
Transition pieces—310 stainless and Hastelloy (Figures 10, 11, 12)
Cross flame tubes—Hastelloy X—improved strength and corrosion resistance
Fuel gas nozzles—Incoloy 800
Cast vane segments—X45 cobalt alloy (Figure 13)
Blade ring segment—Cast 309 stainless—Results on vendor repaired parts were poor. It was discovered later that the vendors do not repair cracks—they only braze over them.

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subsurface defects (see Figures 18 and 19). In one case, a complete row of turbine blades was checked by dye penetrant, revealing no defects. Eddy current probes later detected five cracked blades (see Figure 20). The NDT group has built and stocked a shutdown trailer in order to enable the lab facilities to go to the work, rather than vice versa. This has reduced NDT turnaround time by approximately 30%.

**Mechanical Analyst**—The mechanical analyst's job is multifaceted. Typically, an analyst is assigned a specific machine or group of machines. He learns his machines' particular characteristics and does routine monitoring. He is responsible for emergency maintenance, as well as scheduled overhauls (see Figure 21). Our gas turbines are almost exclusively base load, and they get a hot end inspection once a year and an overhaul every two years. Extensive written and photographic records are kept on each job, to allow later analysis and to ensure that data are not forgotten. Scrutinizing these records can lead to improvements in procedures. A case in point is the removal of the IGV's on a 70MW gas turbine. The manufacturer's recommended procedure involved removal of the covers. Our familiarity and firsthand experience with the machines enabled us to develop a method of replacement which does not require removal. This method alone saves 250 man-hours, plus the associated downtime.

One of the analysts' biggest jobs is preplanning and critical path development. This is the biggest contributor to reduced turnaround time. We can ensure ourselves that the proper amount of manpower is available, as well as tools, spare parts, and supplies. Here again, the idea of keeping the

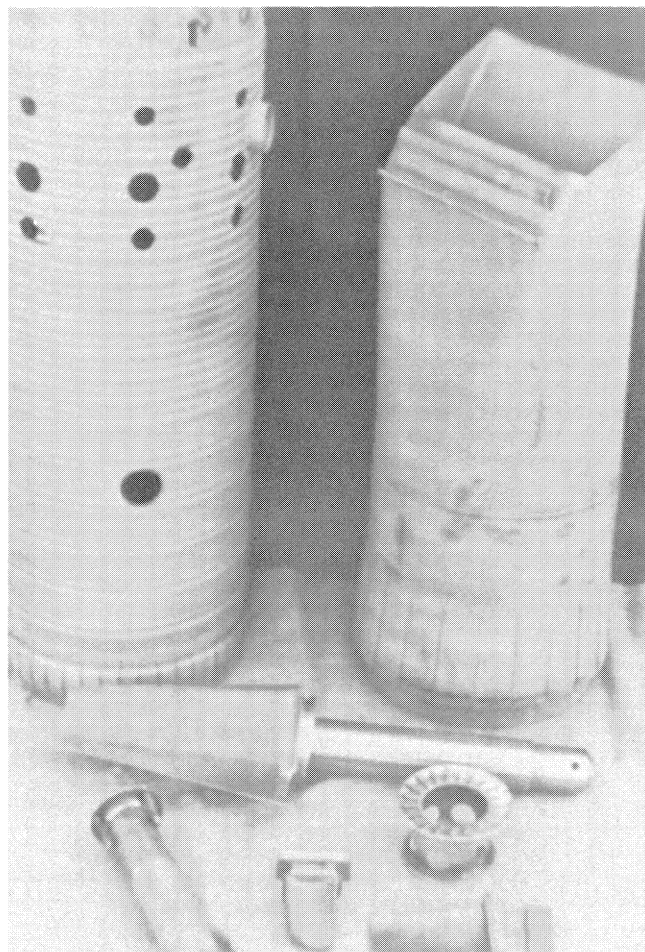


Figure 7. Combustor Parts and Blades Acquired from Alternate Source Vendors.

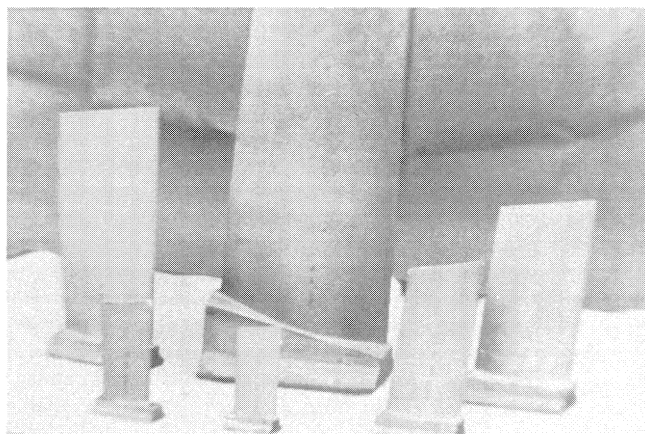


Figure 8. Spray Coated Compressor Blades.

experience "inside the gate" and using it comes into play (see Table 2).

As a coordinator, the analyst's responsibilities include vendor witnessing; all phases of installation, including leveling of sole plates, setting and aligning of equipment, assuring cleanliness of piping, etc.; and verification of trip points and sequencing. He also helps operating personnel to familiarize themselves with the equipment.





Figure 9. IGV Removed from Service Showing Coating Failure and Resulting Corrosion of the Parent Material.

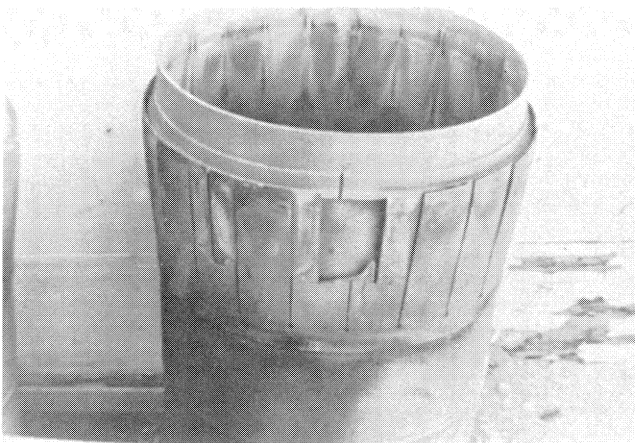


Figure 10. Transition Piece Showing Broken Spring Clips to be Weld Repaired.

The mechanical analyst contributes through phases of gas turbine acquisition, installation, and startup. He is a prime example of the hands-on, in-house philosophy working.

**Mechanical Engineer**—Mechanical engineers are involved in all phases of gas turbine specification and in purchase, testing, installation, commissioning, operation, and troubleshooting. Our gas turbines are bought to conform to API codes as closely as possible. We participate in the UVA

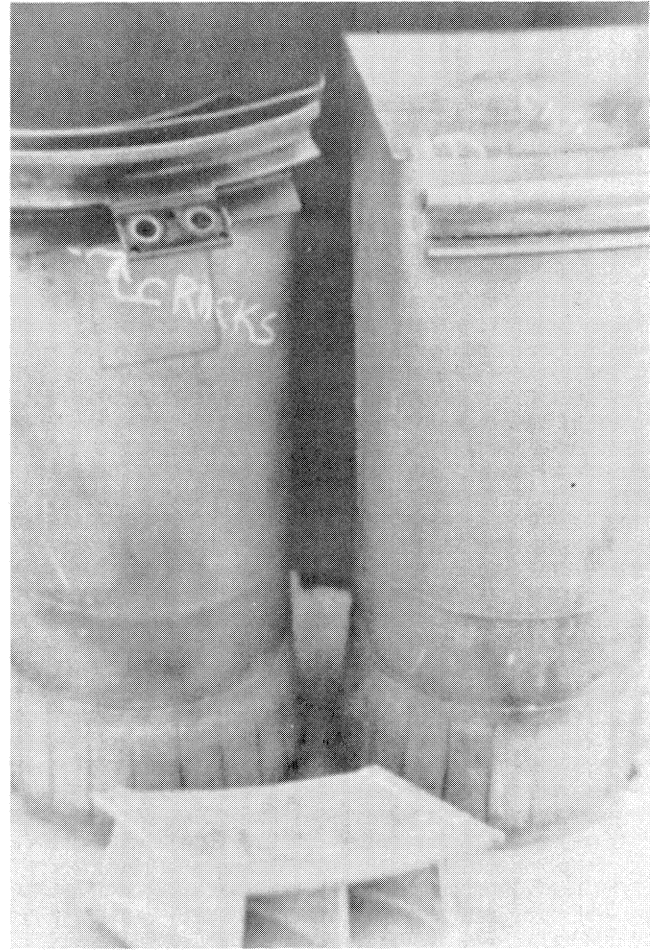


Figure 11. Transition Pieces and Cast Vane Segment After Repair.

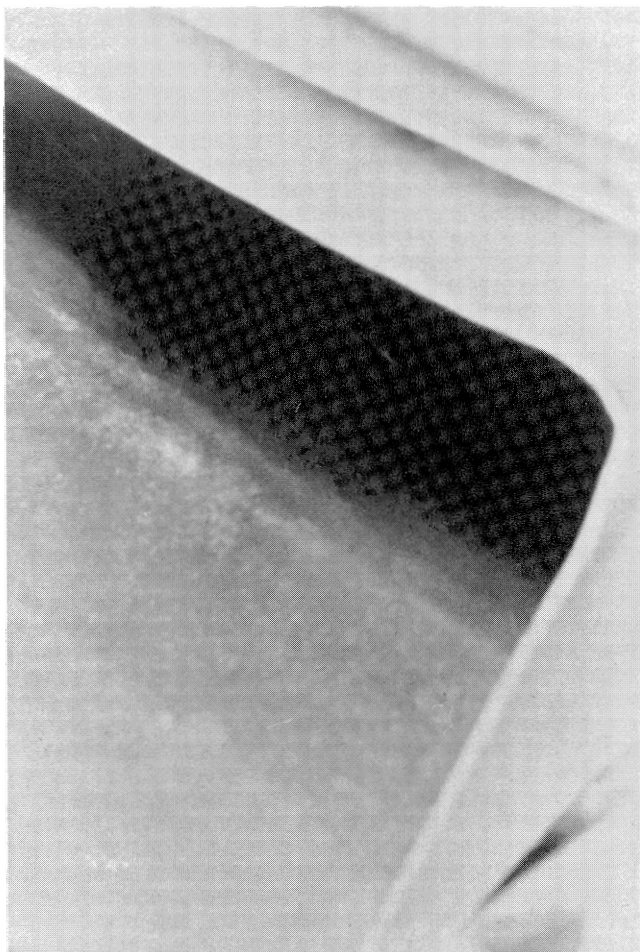
rotor dynamics program, which gives us access to the computer codes necessary for a complete rotor response analysis. An analysis is run on each machine to verify critical speed margins. Torsional critical speed analyses also are made. Mainly for problem solving, the ZORBA program from Northern

*Table 2. Preplanning Activities.*

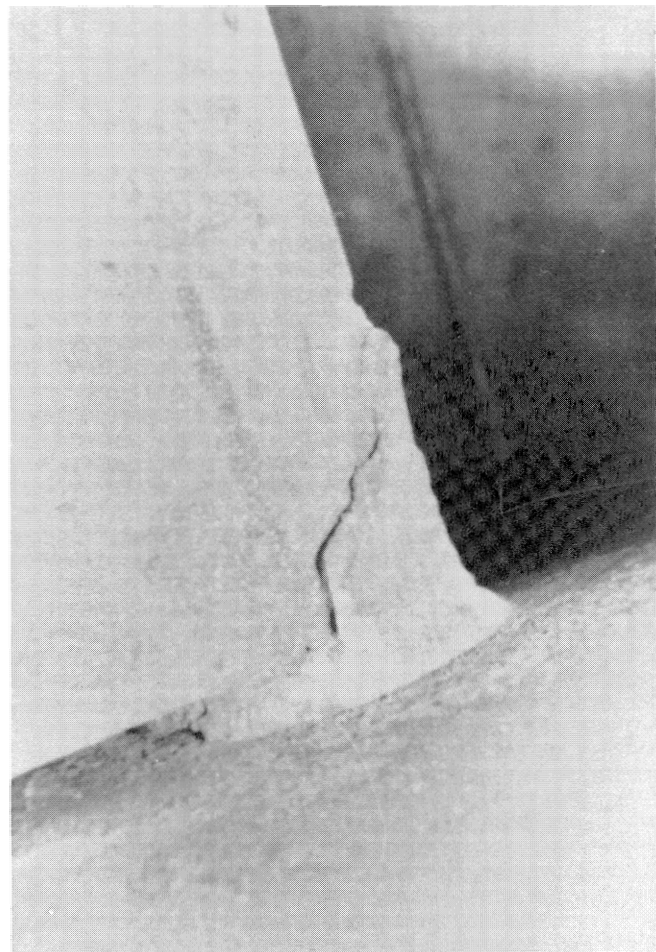
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Machinist labor
Electricians
Instrument people
Insulation removal
Ordering and storing supplies
Organizing tools
Rigging
Sandblasting
NDT inspection
Metallurgical inspection
Machine shop work on auxiliary equipment
Major shop work such as runout checks, balancing, burnishing probe locations, and bore examination of hollow rotors
Locating spare parts and repairing removed parts
Transport
Development of critical path and ensuring that nothing is left to chance

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*Figure 12. Inside of a Transition Piece Showing Burnt Through Hole to be Repaired.*



*Figure 13. Cracked Strut Was Repaired and Inspected by NDT.*

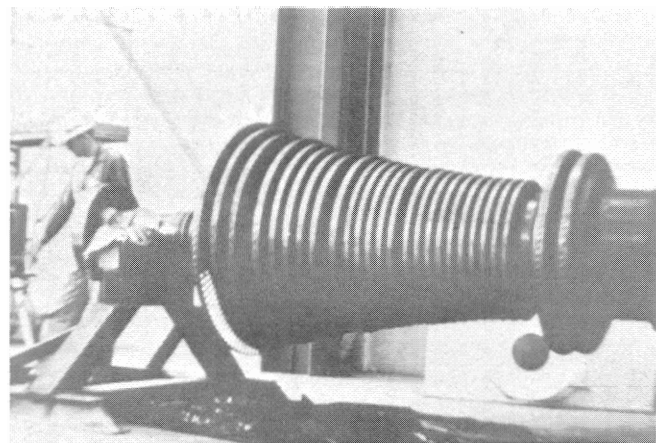
Research and the FLAG program from NASA Lewis Research Center are used for detecting stall points and for performance evaluation.

A critical equipment engineer at the plant follows installation through setting of the sole plates, setting of the equipment, alignment, and startup. These engineers also have plantwide responsibilities giving them maximum exposure and hands-on experience. This wide experience also helps to minimize redundant effort by making the engineers aware of previous work.

Coordination is also a big part of the engineer's job. He works with the other disciplines, consultants, owners, and vendors as needed (see Figure 22).

#### *Results*

1. Gas turbine turnaround time has been reduced approximately 50%.
2. Manpower usage has been reduced approximately 50%.
3. Machine failures have been reduced drastically, with only one gas turbine operating failure in eight years. This failure was caused by operator error—the operator didn't believe the instrumentation.
4. Component life has been extended by careful inspection, metallurgical analysis, rewelding, and heat-treating.



*Figure 14. Steam Turbine Rotor Undergoing Magnetic Particle Inspection.*

#### *Status*

Though all of the objectives have not yet been met, this program is in operation today.

#### **KEYS TO SUCCESS**

There are three keys to the success of this program: personnel selection, spreading of technology, and a multidisci-

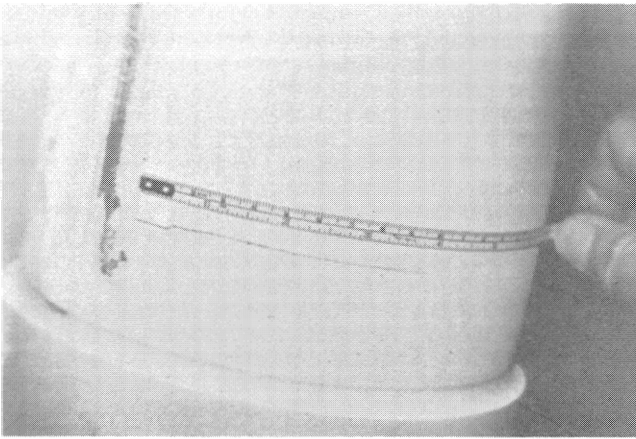


Figure 15. Large Compressor Shaft Showing Crack with Dye Penetrant.

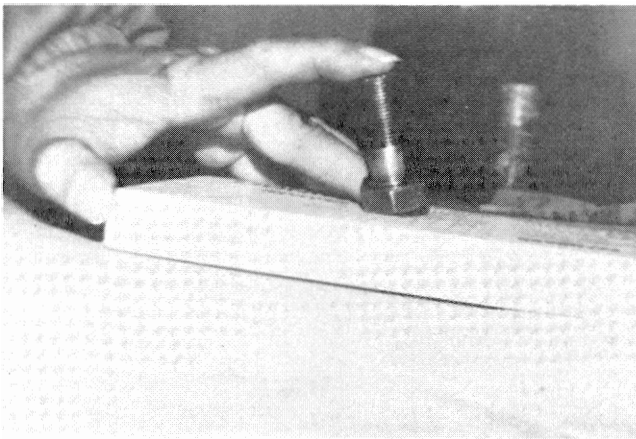


Figure 16. Cracked Fastener Before Inspection.

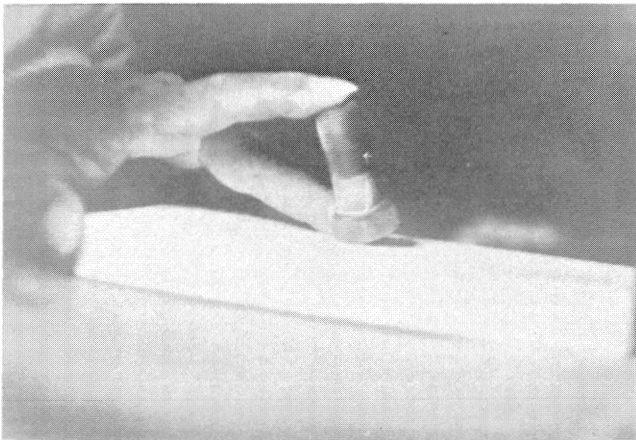


Figure 17. Same Fastener as in Figure 16, With a Crack Detected by Magnetic Particle Inspection.

plinary approach to problem solving:

1. Personnel who have the technical talents needed and who are interested in machinery are selected, and they are kept proficient by being involved in hands-on activities. For example, when gas turbine mechanical analysts are not working on gas turbines, they are working on steam turbines, process compressors, gear boxes or pumps. They become professionals, problem

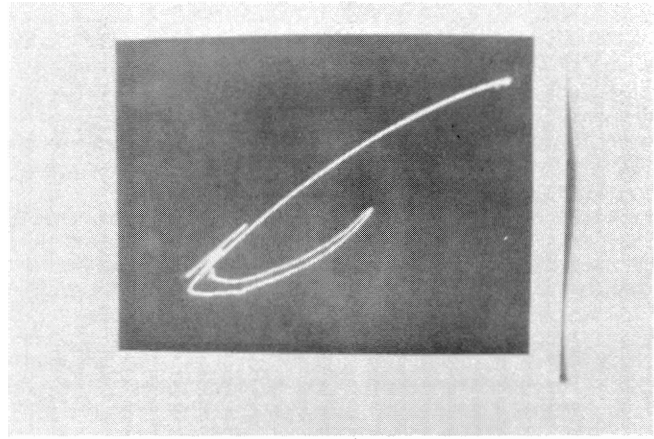


Figure 18. Oscilloscope Trace of Crack Detected by Eddy Current.

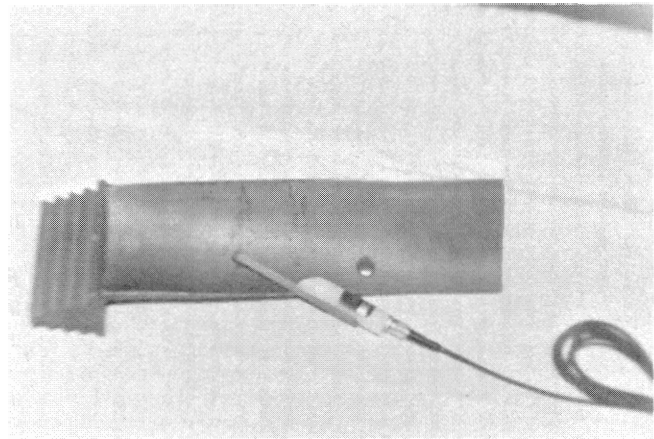


Figure 19. Eddy Current Probe with Test Specimen that Has Known Crack Sizes and Is Used for Calibration.

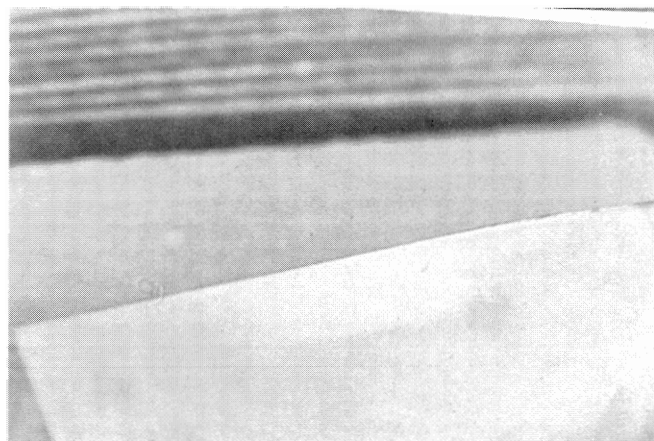


Figure 20. Gas Turbine Blade Showing Cracked Trailing Edge.

solvers, in their areas of responsibility. These analysts often initiate design changes on their own, using the combined talents of other specialists available.

2. Having the involvement of several people in solving problems assures that we are not limited to the abilities of one individual. If one person is missing, it isn't a disaster.



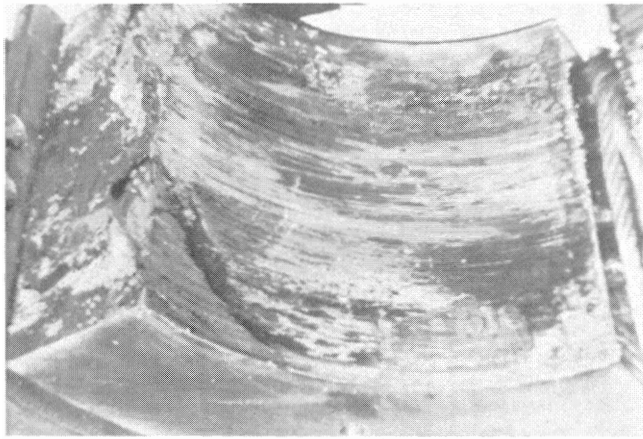


Figure 21. Middle Bearing from a Three Bearing Gas Turbine; Parts and Expertise on Hand Greatly Reduced Repair Time.

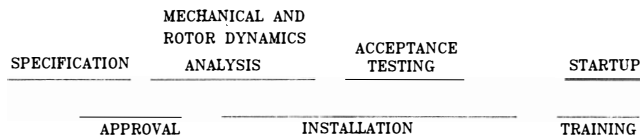


Figure 22. Mechanical Engineering Discipline Functions.

3. A multidisciplinary approach minimizes errors in problem solving. For example, a mechanical problem may be solved, but material or inspection problems may be created simultaneously. A multidisciplinary approach helps to prevent these problems.

### SPINOFFS

A multidisciplinary approach to problem solving leads to maximum use of technical know-how in other process equipment problems. Engineers are allowed to be more creative—to develop new concepts and approaches. When maximum development of individuals is allowed, there is no end to the opportunities to improve performance of production equipment. After engineers get used to being “pushed into the pond,” where they have to “produce or perish,” most of them begin to like it; and if they are not kept challenged, they leave.

### PAYOFF

It would be easy to assume that only large plants can afford such an operation. However, companies wouldn't be in their present environments if they were not making profits.

The people evaluating, procuring, and/or repairing parts for gas turbines contribute enough to convince management that they are some of the most profitable people on the payroll. Technical people should be the biggest profit creators within a manufacturing company. If they aren't, someone is doing something wrong.

Our engineering schools are turning out technical personnel with excellent potential. We are getting some of the best engineering raw material that I have seen in 30 years. If these people are placed in the right atmosphere, trained, and developed, they can grow to be tremendous profit producers, regardless of the size of the plant.

### CONCLUSION

I believe in America; I believe in its technical development. I believe our futures can be fantastic. Our living conditions are limited only by ourselves. We can have the best running manufacturing equipment in the universe—if we will only educate, communicate, and motivate ourselves and others, and stay intimately involved in problem solving.

Don't wait for someone else to do it for you. Be the master of your own ship. Put those engineers and technicians to work. Go home and put your hands on those machines—if a machine is vibrating, let it tingle your feet. It may make you feel so good you will go do something about it—yourself!